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U. S. NAVAL AIR ENGINEERING CENTER

LAKEHURST, NEW JERSEY

NAEC-GSED-95 JUNE 1975

FINAL TECHNICAL REPORT
FEASIBILITY DEMONSTRATION OF USING
PULSE LASER HOLOGRAPHIC TECHNIQUES
TO INSPECT NAVAL AIRCRAFT ENGINE COMPONENTS

CONTRACT N00156-74-C-1580

DEPARTMENT OF THE NAVY ★ NAVAL AIR ENGINEERING CENTER ★

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The feasibility of employing pulsed laser holographic interferometric inspection techniques to inspect turbine blades was investigated. Pulsed laser techniques allow holographic inspection to be deployed in other than a laboratory environment such as in an air rework or maintenance facility. Holographic testing was performed using individual TF41 HP1 turbine blades and assembled T56 HP1 turbine wheels. Several different optical configurations and dynamic loading procedures were evaluated. Inspection of blades in a fully

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assembled wheel showed that locations of artificial "cracks" in the airfoil surface which were on the order of 0.050 long could be clearly resolved when using a transient loading technique.

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AT-SVD-TR-75-9

27 June 1975

Final Report

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Prepared for

Naval Air Engineering Center
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FOREWORD

The work described in this report was sponsored by the Naval Air Engineering Center, Lakehurst, New Jersey. The work was performed by the Advanced Technology Staff of the Space Vehicles Division of TRW Systems Group under the direction of Dr. P. G. Bhuta. The authors wish to thank Dr. Wayne Sule of NAEC for monitoring and guiding the technical efforts of the contract, and D. R. Tomren and J. E. Martija of TRW for their assistance in performing the holographic testing.

J.L.J. & J.E.W.

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1.0 INTRODUCTION AND SUMMARY

The feasibility of employing continuous wave (CW) holographic interferometry for the evaluation of naval aircraft engine components was demonstrated under a previous contract (Ref. 1). In particular, it was shown that defective turbine blades could be identified when inspected individually. The applicability of CW holographic techniques, however, is generally confined to use in a laboratory environment. In order to overcome this restriction, an objective of the present program has been to apply pulsed laser holographic interferometric techniques to the problem of turbine blade inspection. This would allow deployment of a holographic inspection system in an air rework or maintenance facility. In addition, this program has demonstrated the feasibility of performing the inspection without disassembly of the turbine wheel. This can result in a significant savings in time and cost over present inspection methods.

Pulsed laser holographic testing was performed using individual TF41 HP1 turbine blades and with T56 HP1 series 1 and series 3 turbine wheels with blades. A number of optical arrangements were investigated in order to determine the best approach for testing an assembled wheel. Pulsed laser inspection requires use of dynamic loading techniques. These loads must be carefully tailored in order to maximize the number of blades which can be inspected simultaneously. Various dynamic loading procedures were examined and compared. Several of the blades from the series 3 wheel were prepared with artificial "flaws" so that the sensitivity of the inspection procedure could be assessed for the various loading techniques. This consisted of inserting slots of various depths into the leading edge of the blades in order to simulate leading edge cracks. Holograms were made which clearly showed locations of "cracks" .050" deep when using a transient loading technique. Details of all of the testing, as well as photographs of representative holograms, are included in this report.

These tests have established that it is feasible to use pulsed laser holographic interferometry techniques to inspect turbine blades

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which are mounted in a fully assembled wheel. The extremely short exposure times of the pulsed laser and the dynamic loading of the turbine wheel eliminate the environmental constraints which severely limit the application of older holographic techniques. Before fielding this system, it remains necessary to determine the most appropriate optical configuration and dynamic loading technique for maintenance applications. The system must be engineered in order to maximize its sensitivity and reliability while at the same time simplifying the test procedure.

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2.0 PULSED LASER HOLOGRAPHIC INTERFEROMETRY

The use of continuous wave (CW) holographic inspection techniques for evaluating engine components was demonstrated under a previous contract (Contract N62269-72-C-0400) (Ref. 1). These techniques provide a powerful diagnostic tool for evaluating materials and as such, they were employed to a limited extent during this program. However, the applicability of CW holography is generally restricted to a laboratory environment. This is because of the mechanical stability required to make a hologram. None of the optical elements can be allowed to move more than a fraction of the optical wavelength during the exposure of the hologram. Typical exposure times for CW holograms may be as long as several seconds. This necessitates working in a very quiet, vibration free, temperature stable environment. A massive granite table is usually employed as a stable platform for the optical elements. These limitations are unacceptable for an inspection tool which must operate in a maintenance environment.

Pulsed laser holographic interferometry overcomes the environmental limitations discussed above. The key element which has been substituted is a pulsed laser, such as a Q-switched ruby laser. The ruby laser produces enough light to expose a hologram in an extremely short duration pulse, typically less than 50 nanoseconds. This is short enough to effectively "freeze" any motion or vibration in the apparatus or test specimen during the holographic exposure. The laser can be programmed to produce two pulses in less than a millisecond, so that a double-pulse hologram can be made of a dynamic event. The resulting interferometric fringe pattern records the differential displacement of the object's surface which has occurred between the two laser pulses. As in CW holography, the individual fringes represent contours of displacement of the surface. The fringe patterns thus reveal how the object has responded, between two points in time, to the applied dynamic load. An example of this technique applied to a simple structure is shown in Figure 1. This figure shows a set of pulsed laser holographic interferograms which were made of an axisymmetric flexural wave created in a flat

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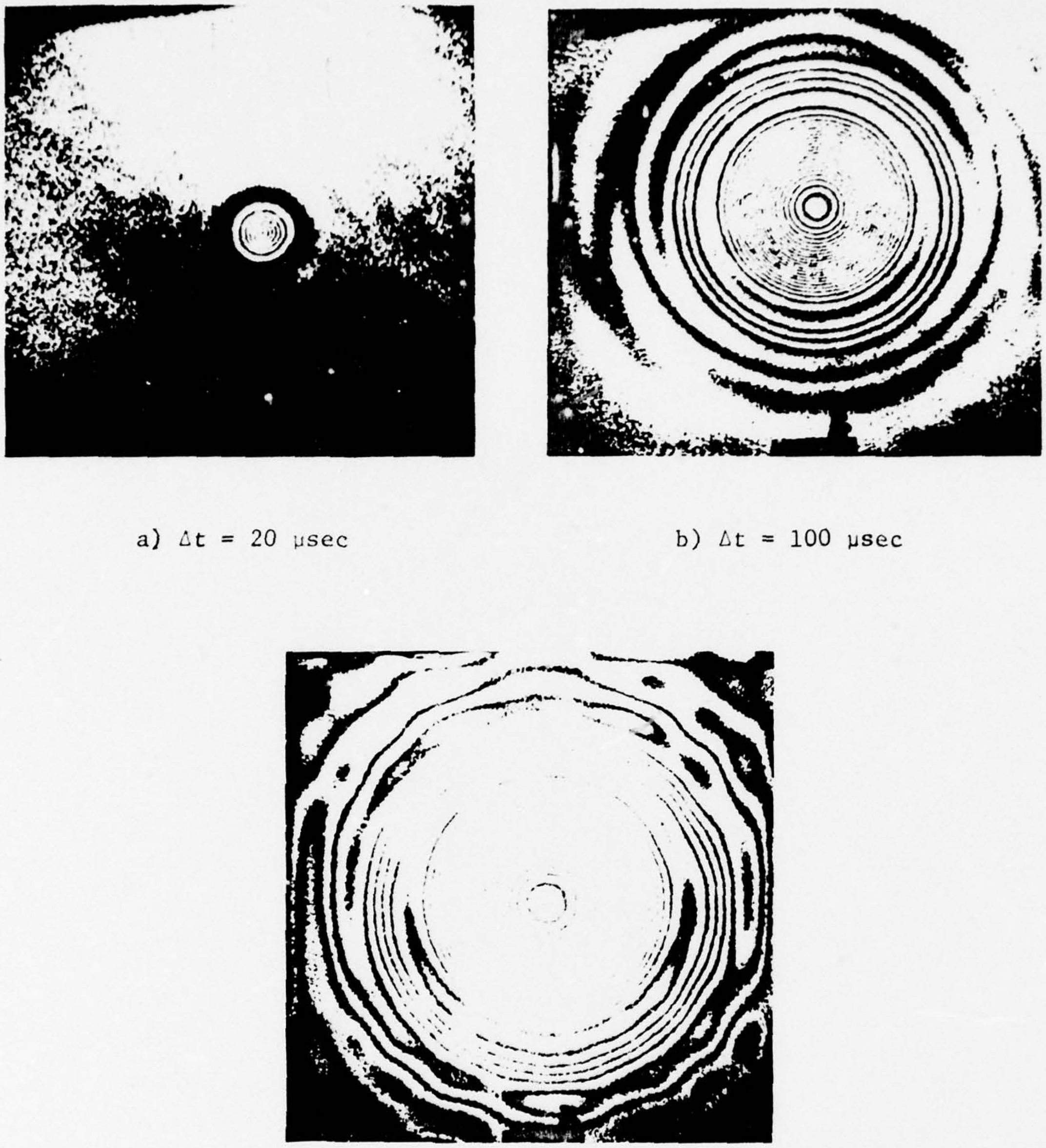
aluminum plate by striking it normally in the center with a spherical ballistic pendulum. The pendulum struck the plate on the back side. Interferograms of the bending wave were obtained from several experiments. In each case the first exposure was made just prior to the impact and the second exposure a short time thereafter. The fringe patterns are very uniform and symmetrical because of the homogeneity of the aluminum plate (Ref. 2). If there were a flaw or crack in the plate, it would be exhibited by nonuniform or discontinuous fringe patterns. This is the basic idea behind holographic nondestructive testing.

The dynamic nature of the pulsed laser holographic technique is its most significant advantage and, at the same time, creates the most problems with its application to inspection of materials. With CW holography, static loads are applied which can be carefully tailored to produce an optimum interferometric fringe pattern. The end effect of a dynamic load is often less predictable. Furthermore, very precise timing of the holographic exposures is required in order to produce results which can be readily interpreted. It is important to bear in mind that holographic interferometry only measures the response of an object's surface to an applied structural load. A flaw or anomaly in the structure will be detected by this technique only if its presence will alter the manner in which the surface responds to the load. Clearly, choosing a proper loading technique is essential to the optimum application of holographic inspection.



a) Δt = 20 μsec

b) Δt = 100 μsec

c) Δt = 150 μsec

Figure 1: Pulsed laser holographic interferograms of an axisymmetric flexural wave created in a flat aluminum plate by striking it normally in the center (rear side) with a spherical ballistic pendulum. In each case, the first exposure was made just prior to the impact and the second exposure was made a) 20 μsec; b) 100 μsec; and c) 150 μsec after the impact.

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3.0 DYNAMIC STRUCTURAL LOADING FOR HOLOGRAPHIC INSPECTION

The loading technique chosen for holographic inspection must meet several criteria. First of all, it must be repeatable so that the inspection results from specimen to specimen can be directly compared and valid conclusions can be drawn from them. Second, the load must cause the specimen to respond such that a structural flaw or anomaly will affect the holographic fringe pattern taken of the specimen's surface deformation. Third, the amplitude of the load must be so small as to preclude any possibility of permanent change or damage to the specimen. During this program, three types of dynamic loading techniques were employed, all of which meet the conditions stated above. These techniques are described in greater detail in the following sections.

3.1 Incremental Loading

In CW holography, the object is incrementally loaded, i.e., an increment of force or torque is applied to the object, so as to convert it from one static state to another. The two holographic exposures must be made when the object is at rest, one exposure before and the other after the load is applied. By substituting a pulsed laser for the CW laser, it is no longer necessary for the object to be at rest during the exposure. In fact, by timing the pulsed laser properly, it is possible to capture the object at two times while it is undergoing the transition between the two static states. The importance of this is that if follows that most "CW" loading techniques can be employed in a "dynamic" manner thus removing the environmental constraints described in Section 2.0. The amplitude and direction of this type of loading procedure can be made to be very repeatable but some difficulties may occur when trying to precisely time the laser pulse to the application of the load.

During the course of this program, static loading techniques were used to assess the response of the blades to various levels of strain. The objective was to determine the magnitude of the force necessary to produce an interferometric fringe pattern which was adequate to inspect

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the blades. A fixture was built which could be attached to a blade mounted on the wheel, and by which a bending load, torsional load, or a combination of these two could be applied.

Information was also obtained about the orientation of the fringes produced by various types of loading. Simple analyses and previous observations have indicated that a bending load produces fringes which are aligned laterally across the blade, as rungs on a ladder. This kind of fringe pattern is not likely to reveal cracks in the leading edge of a turbine blade. A pure torsion applied to the blade will give rise to fringes which run, for the most part, up and down the length of the blade. A combination of bending and torsion will produce fringes which run askew of the axis of the blade, at angles dependent upon the ratio of the bending and torsion components. The use of the special loading fixture made it easy to produce these various fringe patterns at will, yielding greater data on the problem of the proper tailoring of fringe patterns for optimum crack detection.

3.2 Vibratory Loading

Introducing a steady-state vibration into the test specimen is another way of applying a dynamic load. An appropriate electro-mechanical or piezoelectric device is used to excite the object to a periodic vibration. The laser is pulsed at two times between which the structure has experienced a relative displacement. The frequency of excitation is preferably chosen to coincide with a resonance of the structure so that maximum energy can be coupled into it.

At lower frequencies (up to about 5 KHz) an electro-mechanical transducer, such as the one shown in Figure 2, can be used to couple relatively high power levels into the object. However, higher frequencies are generally better for detecting small structural flaws in stiff structures such as the turbine blades of interest in this program. Piezoelectric crystals can be used to generate much higher frequencies, but the power produced by these devices is quite small. Figure 2 shows a large piezoelectric transducer which was used to excite the turbine

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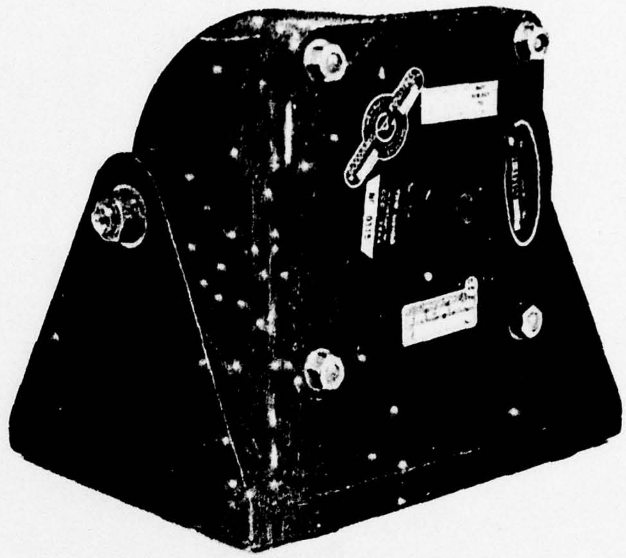
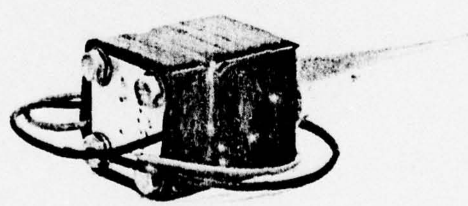


(a) Electro-mechanical transducer



(b) Piezoelectric transducer with acoustic horn coupler

Figure 2: Two devices used for generating a vibratory load in a structure. The electro-mechanical transducer, (a), is primarily a low frequency (less than 5 KHz) device while the piezoelectric transducer (with acoustic horn coupler), (b) works better at higher frequencies.

wheels during this program. It was coupled to the wheel through the acoustic horn (shown in the figure) in order to maximize the transmitted energy.

The principle advantage of using a steady-state vibrational load is its repeatability. The periodicity of the input greatly simplifies the timing problems. The disadvantages are the small deflections which are obtained and the difficulty in producing a fringe pattern which allows the entire object to be inspected. It must be pointed out that no deflection occurs at the nodal points of the vibration and therefore, no information is obtained concerning these points.

3.3 Transient Loading

A third method for dynamically loading a structure is to employ a mechanical impulse in order to initiate a transient stress wave. The two holographic exposures are made as the stress wave is traveling through the structure, recording its response at two different states of stress. An example of this technique applied to a simple, homogeneous structure was illustrated in Figure 1 which showed a flat aluminum plate which had been struck with a ballistic pendulum. This simple pendulum impact procedure has proved to be one of the more successful loading techniques for pulsed laser holographic inspection. It is highly repeatable and produces large localized strains in the structure. The fringe patterns produced in complex structures exhibit an apparent randomness, however, the locations of structural anomalies remain easily detectable. Structural cracks are generally characterized by either discontinuities or abrupt changes in slope of the interferometric fringes. Locally weak areas, such as a fatigued area in a metallic structure or a weak bond in a composite, are usually characterized by a dense pattern of erratic fringes.

As stated above, the pendulum impact is very repeatable and it is straightforward to calculate the energy transferred to the test structure. However, there are limitations placed on the orientation of the test structure. Clearly, the pendulum can't strike it from below. In

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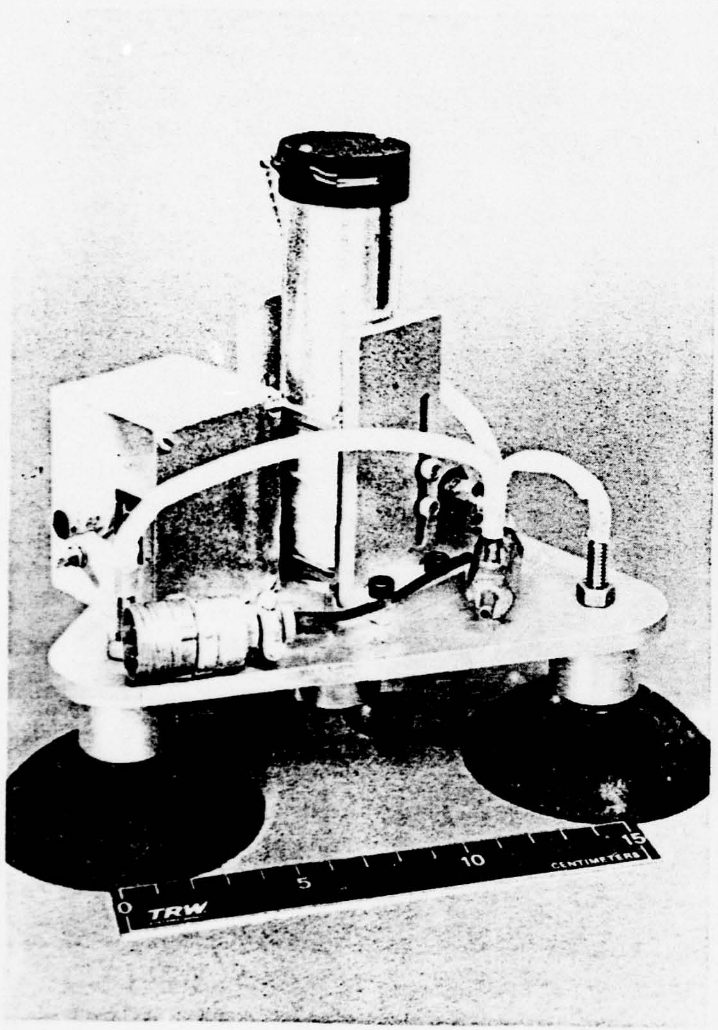
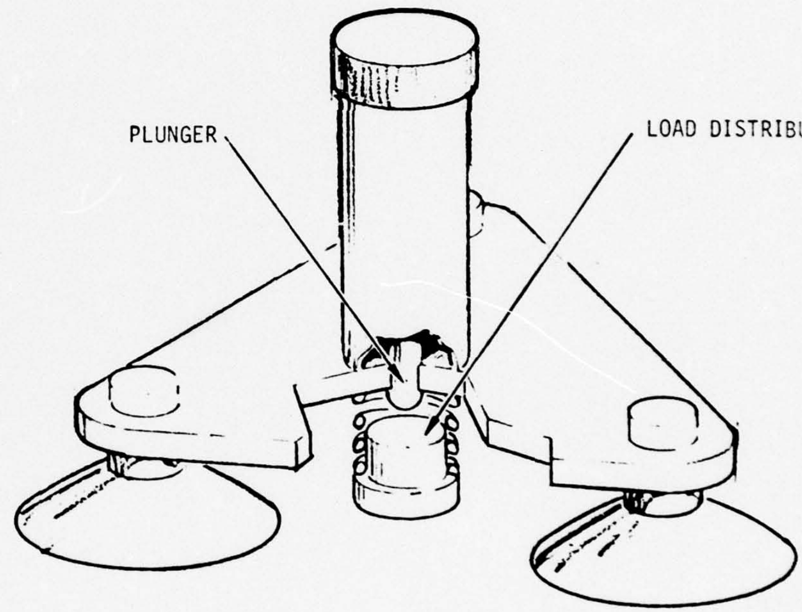
addition, there are timing limitations connected with the pendulum impact technique, which accrue from using the ball-structure contact as an electrical switch to start the timing sequence of the laser. The first 800 microseconds of this sequence are used up in "pumping" the ruby rod to a lasing condition. Meanwhile, the stress wave in the structure has "aged", resulting in lower strain levels. The sensitivity of this technique for crack detection is usually higher at shorter times after the impact. This timing problem can be overcome only by using an elaborate beam-break arrangement which may introduce other problems of its own (Ref. 3).

TRW has developed an electromagnetic impulser which employs the same principles of transient wave initiation as the pendulum but without the limitations described above (Ref. 4). The impulser, shown in Figure 3a, utilizes a solenoid to deliver an impact to the test structure. Electrical energy is stored in a capacitor which, on command, is discharged into the solenoid coil. This accelerates the plunger at a rate dependent upon the voltage level to which the capacitor is charged. The operating range permits a wide variation in deliverable impulse. The impulser can be attached to the test structure by means of three suction cups on which a continuous vacuum is drawn or the suction cups can be removed and the impulser attached directly to the structure. As indicated by the cutaway drawing, Figure 3b, the plunger does not strike the structure directly, but the impact is transmitted through a load distribution block so as to prevent damage to the structure. The block is spring-loaded and self-aligning. The device can be operated in any orientation. The timing problems referred to above are eliminated by a special timing device which is built into the impulser. In conjunction with the delay circuit on the laser console, this device allows the laser to be fired even before the stress wave starts, if desirable, or at any point in time thereafter. The load derived from the impulser differs little from that derived from the pendulum. During the course of this program, both the pendulum and the electro-mechanical impulser were employed as loading techniques.



a) Impulser



b) Cutaway view of impulser

Figure 3: TRW's electro-magnetic impulser used for initiating a traveling stress wave for transient loading of a structure.

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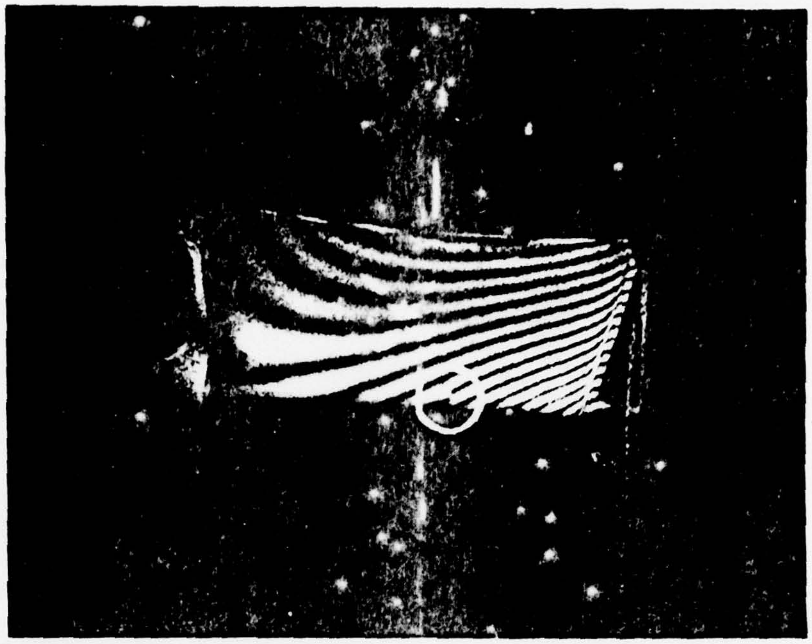
4.0 INSPECTION PROCEDURES AND RESULTS

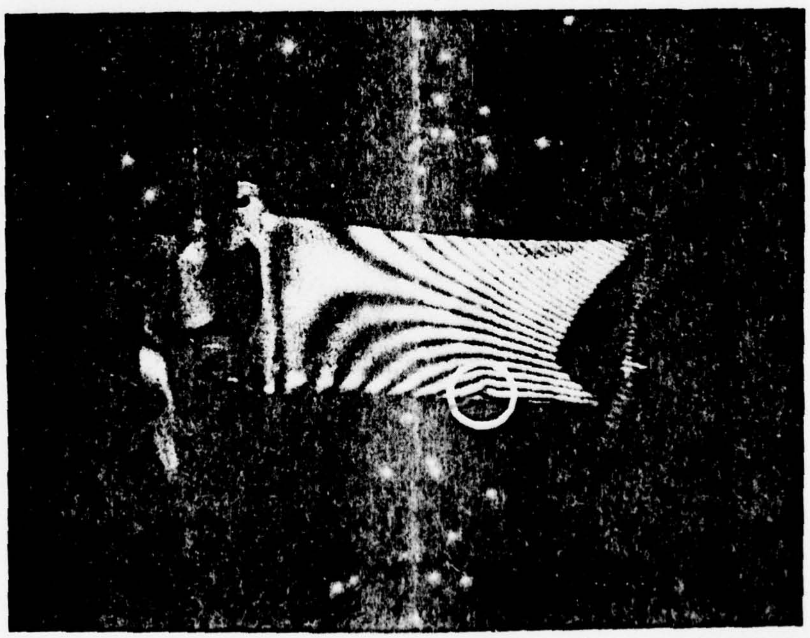
The goal of this program was to determine the feasibility of inspecting complete or partial turbine wheel assemblies using pulsed laser holographic interferometry and dynamic loading techniques. The testing period was divided into three phases. During the first phase, the ability to reproduce prior CW holographic results on TF41 HP1 turbine blades using pulsed laser techniques was confirmed. The second phase utilized a T56 HP1 (series 1) turbine wheel and consisted primarily of investigating the effectiveness of various optical configurations and loading techniques. These investigations were continued into the third phase using a T56 HP1 (series 3) turbine wheel. The sensitivity of the holographic inspection technique was also considered during this phase. The actual test procedures and results are discussed in the following sections.

4.1 Inspection of Individual TF41 HP1 Turbine Blades

Under Contract N62269-72-C0400 (Ref. 1), a set of eleven TF41 HP1 turbine blades were inspected using CW holographic interferometry. Several of these blades contained cracks in the airfoil and tip areas which were recorded by CW double exposure holography using a static load. In order to provide a direct comparison between the CW and pulsed techniques, this set of eleven TF41 blades was re-inspected using pulsed laser holographic interferometry. The blades were mounted individually in a holding fixture and a dynamic impulse was then applied to the blade by impacting the holding fixture with a small pendulum. The ruby laser was pulsed twice (∿50 μsec separated the pulses) during the time in which the impulse was traveling through the blade. By adjusting the timing of the laser pulses, the orientation of the resulting fringe pattern could be "fine-tuned" to optimize the flaw detection. The results of these tests compared very favorably with the previous results. Figure 4 shows photographs of holograms of a TF41 blade (blade #1 in Ref. 1) under both continuous wave and pulsed laser holographic inspection. The crack on the leading edge (circled) is revealed by both techniques. Pulsed laser holograms of the other blades of the set produced similar results.



(a)



(b)

Figure 4: (a) Continuous wave and (b) pulsed laser holographic interferograms of a TF41 HP1 turbine blade showing location (circle) of crack on the leading edge.

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4.2 Inspection of Assembled T56 HP1 (Series 1) Turbine Wheel

At the outset of this program, it was decided to focus the effort on the inspection of T56 HP1 turbine blades. A used series 1 wheel complete with blades was obtained from NAEC for this purpose. The wheel contained no new blades, and excepting that several of the blades were broken, none were known to have defects. The wheel had not been subjected to prior inspection. A fixture was fabricated which allowed the wheel to be mounted onto a large positioning device which has rotational adjustments about three axes. This device provides the support required for the holographic inpsection and at the same time allows the wheel to be easily repositioned as needed. Figure 5 shows the turbine wheel mounted to the positioning device.

The initial effort included several possible optical configurations in order to determine how many blades could be inspected simultaneously while mounted on the turbine wheel. One basic limitation arises from the curvature of the wheel and the constantly changing view of the blades. For example, with the hologram positioned to show the blades directly, the upper surfaces of the leading edges of only ten blades can be viewed at once. It is possible to illuminate more than twenty blades simultaneously, but not all of them appear at a reasonable viewing angle.

One approach which was found to overcome this limitation employed several mirrors placed so that the view angle could be tailored for the changing blade orientations. The mirrors were located between the blades and the hologram. A small mirror was placed adjacent to the blades and adjusted to optimize the view of only three or four blades. A second mirror was placed next to the first, but its orientation set to optimize the view of the next group of blades. It was found that by extending this to more mirrors, an excellent view could be obtained of as many as twenty blades in a single hologram. It was determined that this technique could be extended one step further with the addition of a second set of mirrors on the opposite side of the blades. The hologram was placed opposite the blade tips so that it could view both sets of mirrors. In

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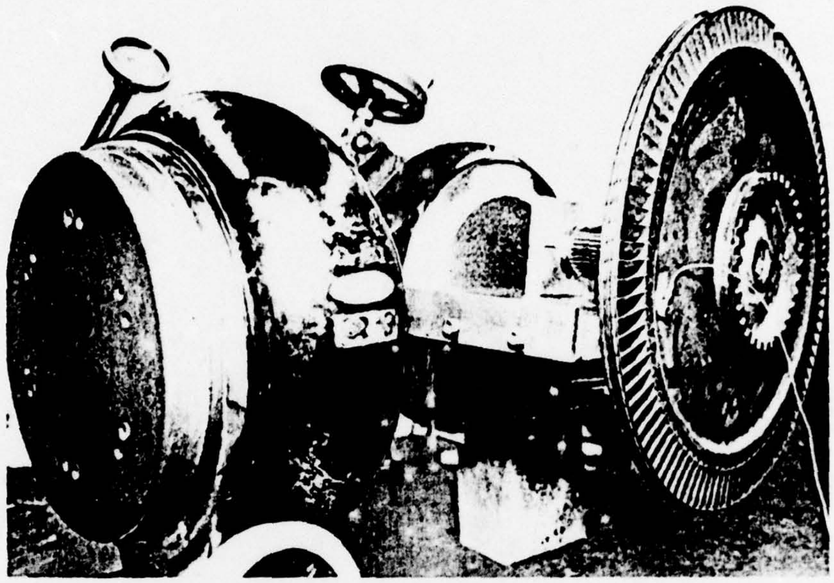
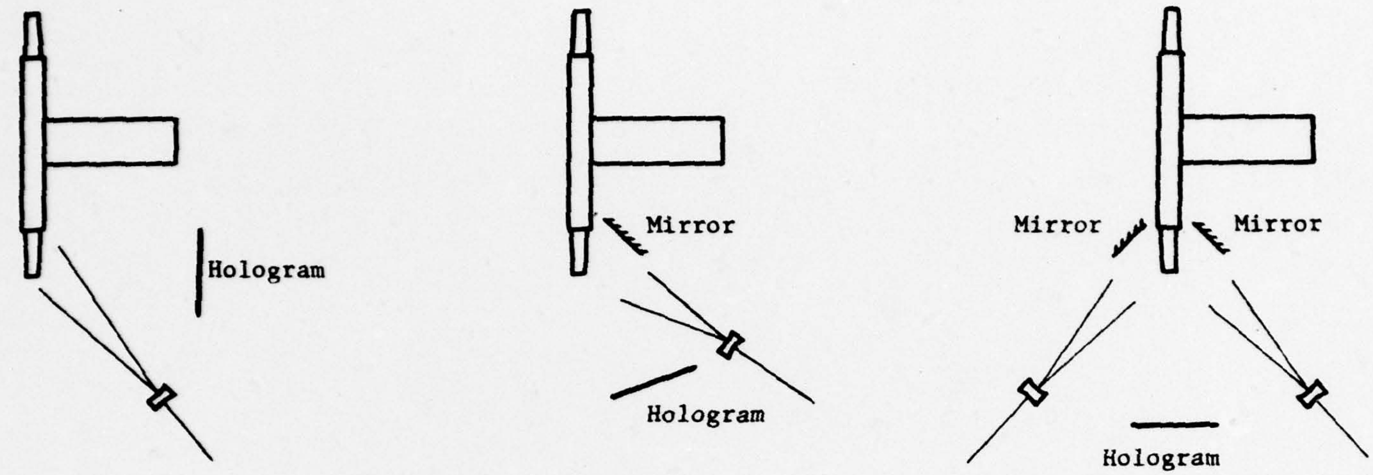


Figure 5: T56 HP1 (series 1) turbine wheel mounted on three-axis positioning device. The small accelerometer attached to the wheel was used to synchronize the pulsed laser with the dynamic impulse in the wheel.

this manner, both sides of the entire airfoil surfaces, as well as the blade tips of up to twenty blades, could be inspected through a single hologram. Figure 6 illustrates schematically these various optical configurations. Figure 7 shows how the blades appear when viewed through the double mirror arrangement. As the viewing system becomes more complex, the problem of properly illuminating the blades also grows. Clearly, some tradeoffs need to be made in order to reduce the complexity of the optical configuration. It should be noted that simpler optical configurations were employed during the later stages of this program when loading techniques were under investigation. Most of the holograms were made using either a single viewing mirror or with the hologram positioned for direct viewing of the blades.

Pulsed laser holographic interferograms were made of the series 1 wheel using both vibratory and transient loading techniques. The



a) Direct viewing

b) Single mirror configuration

c) Double mirror configuration

Figure 6: Three optical configurations for viewing turbine blades mounted on the wheel: a) Hologram positioned to view the blades directly; b) Use of one or more mirrors to optimize view of one side of blades; c) Use of a double set of mirrors so that both sides of the blades can be inspected simultaneously.

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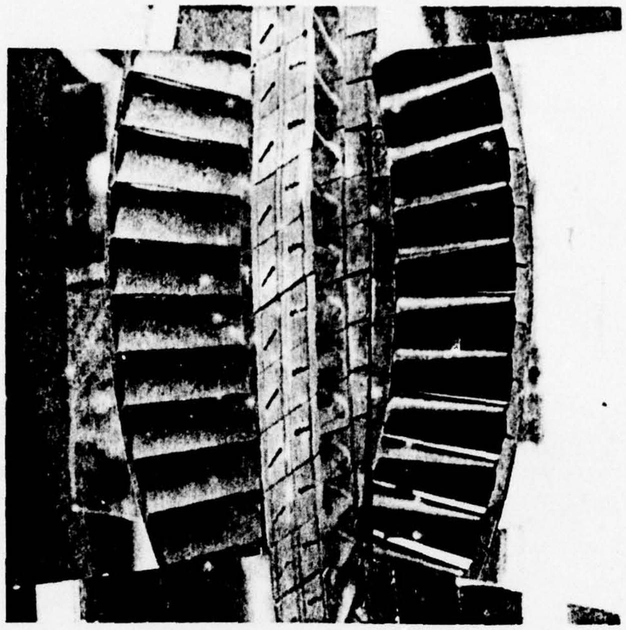

Figure 7: View of both sides of mounted turbine blades and tips from position of hologram when using the double mirror configuration illustrated in Figure 6c.

electro-mechanical transducer, shown in Figure 2a, was used to drive the assembled wheel at various frequencies which produced resonances. The load was introduced at several locations on the wheel. Double exposure holograms made under these conditions produced good, usable fringe patterns on the blades.

Tests were also performed using the pendulum impact technique to load the wheel. A 220 gram steel ball was used to impact the wheel at several locations away from the center and directly at the center using a load distribution block which was attached there. The energy input was varied by changing the drop height of the ball. By adjusting the impact location, drop height and laser timing, the resultant fringe pattern could be optimized for several adjacent blades simultaneously. A representative hologram of this series is shown in Figure 8.

Both of the loading techniques used with this wheel produced suitable fringe patterns, however, none of the holograms exhibited any anomalies which would indicate the presence of a flawed blade. Since there were

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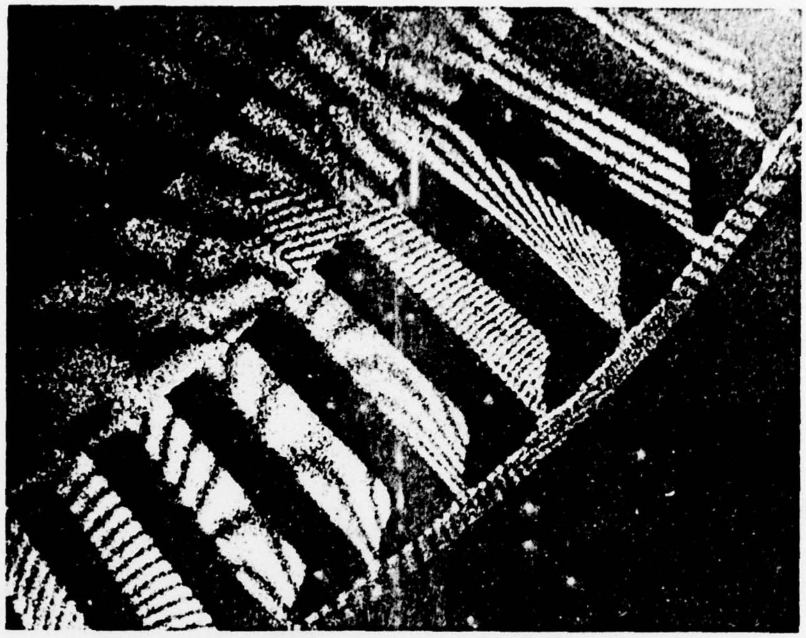

Figure 8: Holographic interferogram of T56 HP1 series 1 wheel using a pendulum to initiate a transient load.

no known defects in the blades tested, no data on the sensitivity of the technique had been obtained. In order to obtain data of this sort, it became necessary to obtain flawed blades or to have some blades specially prepared with artificial flaws. This was done with blades from the series 3 wheel and is described in the next section.

4.3 Inspection of Assembled T56 HP1 (Series 3) Turbine Wheel

About midway through this program, it was determined that the newer series 3 wheel would be a more appropriate test specimen than the series 1 wheel. A series 3 wheel with a partial set of blades was obtained from NARF/Alameda. Some testing was done with this partial assembly until subsequent receipt of enough blades to complete the set. One difference exists between this and the older wheel which has a significant effect on the holographic results. This is that the blades of the series 3 wheel are held very loosely and secured in place with metal clips. The blades of the series 1 wheel were held very tightly. The result

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is that as the dynamic load is transferred from the series 3 wheel to the blades, only the low frequencies tend to be transmitted. As mentioned earlier, high frequencies are better suited for detecting small structural flaws in the blades. It was also found that sometimes the blades responded by rigidly rotating in their mounts.

The application of a preload which prevents the movement of the blade will alleviate this problem. Two types of preloads were used with a fair degree of success. In the first case, a small wedge was inserted between two of the blades to prevent rotating movement. This solved the immediate problem, especially when only a partial set of blades were available, but it is doubtful that such a technique could be employed in an inspection system. A better approach was to place a tight band around the circumference of the wheel, applying a radially inward force on the blades. Most of the tests, using the full wheel were made with this band providing a preload on the blades.

Blades having flaws of known sizes were needed in order to obtain data on the sensitivity of the holographic tests. Because of the difficulty in obtaining blades with natural flaws, techniques for inserting artificial flaws of known sizes into the leading edges of the blades were investigated. It was determined that a slot measuring less than .005" wide could be made in the blade using an Elox machine, a spark erosion process. This technique was employed to create "cracks" of varying depths in several of the blades. A "crack" consisted of a shallow slot in the leading edge of the blade, and was located about midway between the root and the tip. The slot was oriented across the leading edge, transverse to the mean plane of the blade. The slots varied from .020" deep to .075" deep. The width was held constant as this parameter has a neglibible effect on the strength of the blade.

Several of the T56 (series 3) blades were tested individually under static incremental loads and their responses were compared to those of similar tests previously performed using the TF41 blades. The .020" "flaw" inserted in one of the blades was thus detected when placed under a combined bending and torsional load. It was found that the T56 blades

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required greater loads to produce comparable fringe patterns. This would indicate that larger dynamic inputs are required for these blades.

At this point, all of the blades were reinstalled into the wheel for testing of the complete assembly. Earlier tests with vibratory loading using the electro-mechanical transducer (discussed in Section 4.2) had indicated that higher frequencies were desirable. A piezoelectric transducer, shown in Figure 2, which was capable of operating in the 10 to 65 KHz range was obtained. This transducer was coupled to the wheel through an acoustic horn. Ten structural resonances were found within the operating range of this device. Although three or four blades could be excited simultaneously in this manner, the power levels were inadequate for detecting any of the artificial flaws in the blades.

It was decided to return to the transient loading technique. The TRW electro-mechanical impulser was used instead of the pendulum because of the greater range of pulse amplitudes which could be achieved and the relative simplicity of the timing procedures. Holograms were made with the impulser attached to the wheel at several locations between the rim and the hub. One of the resulting holograms of fringe patterns on a group of unflawed blades is shown in Figure 9. This hologram was made using the single mirror optical arrangement illustrated in Figure 6. The blade tips are directly visible on the left and the reflected image of their leading edges and concave surfaces are seen to the right.

By varying the timing, impulse amplitude and location of the impulser, the fringe pattern could be optimized so that the .050" and .075" deep artificial "cracks" could be detected. Figure 10 shows a hologram where the locations of both of these "cracks" can be readily seen. For this hologram, the impulser was attached to the wheel midway between the rim and the hub at about a 90° rotation from the blades to be inspected. The optics were arranged for direct viewing. Although only seven blades are seen in the figure, the leading edges of sixteen blades are visible in the original hologram. One of the problems which is evident in this figure is that the orientations of the fringe patterns differ markedly from blade to blade. This was alleviated by moving the impulser to the

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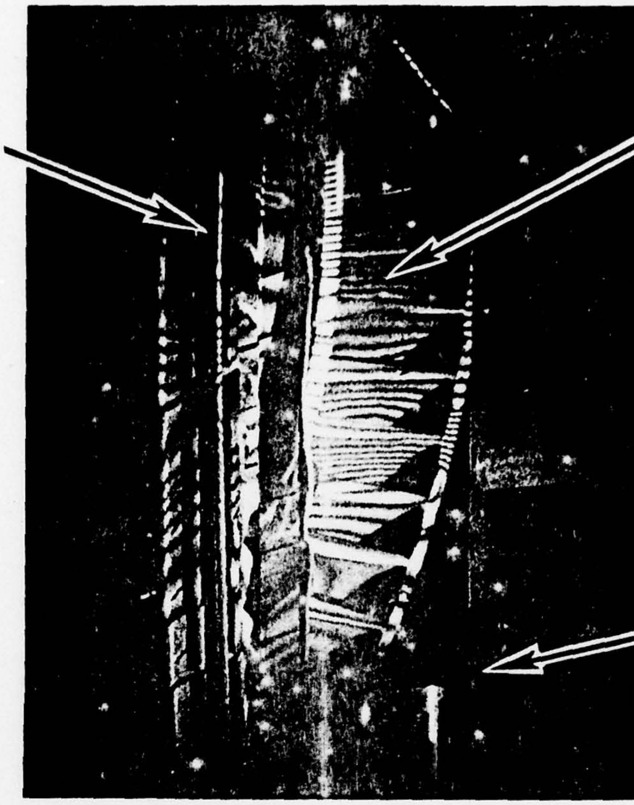

Figure 9: Holographic interferogram of a segment of the assembled series 3 wheel. The blade tips are directly visible on the left and the reflected image of their leading edges and concave surfaces are on the right.

axis (hub) of the wheel. Figure 11 shows the series 3 wheel with the impulser attached on the axis. The rectangular load distribution block is visible between the impulser and the wheel. Less energy was transmitted to the blades in this arrangement making it necessary to operate the impulser near its maximum amplitude. Figure 12 shows a resulting hologram where again the .050" and .075" deep "cracks" are visible. This time, however, the fringe patterns on all of the blades have similar orientations. This is a necessary requirement in order to inspect more blades simultaneously. The "cracks" having depths less than .050" were not detected in these tests. It is thought that higher load levels are necessary to increase the sensitivity for detecting smaller flaws.

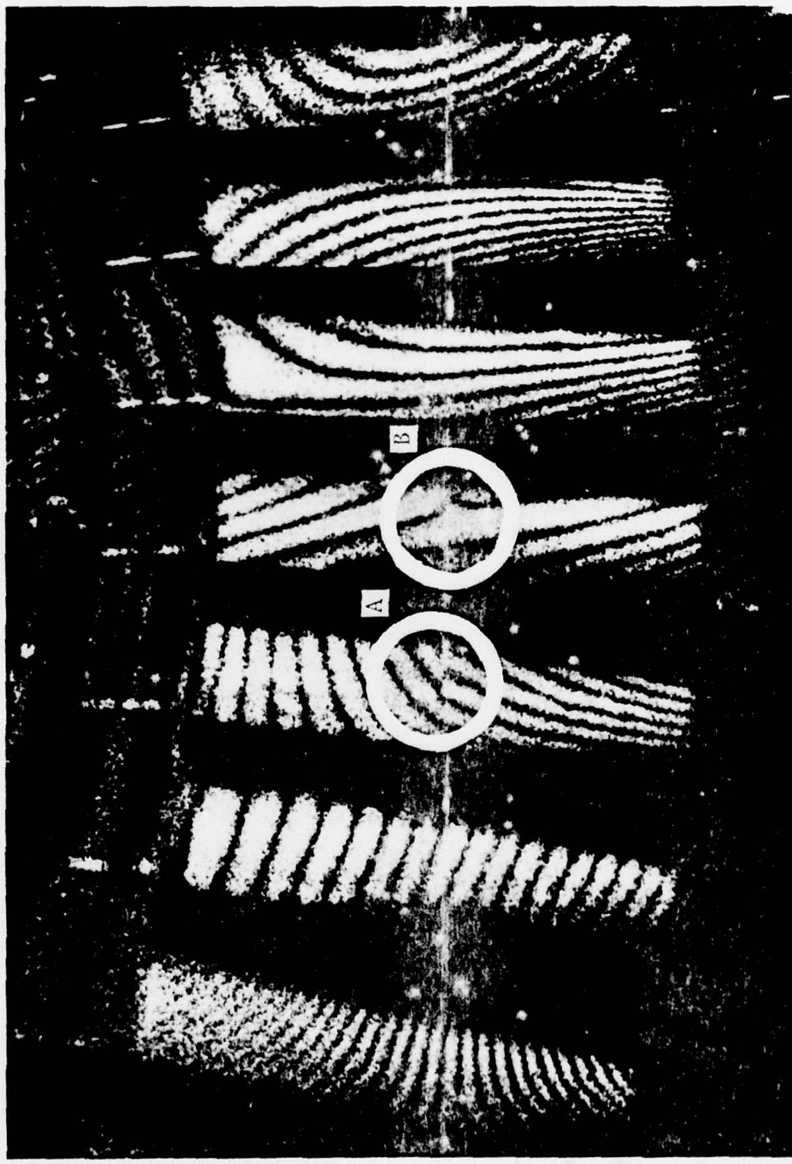

Figure 10: Holographic interferogram of T56 HP1 (series 3) wheel showing locations (circled) of artificial "flaws" in the leading edges of two of the blades. "Flaw" A is .075" deep and B is .050" deep.

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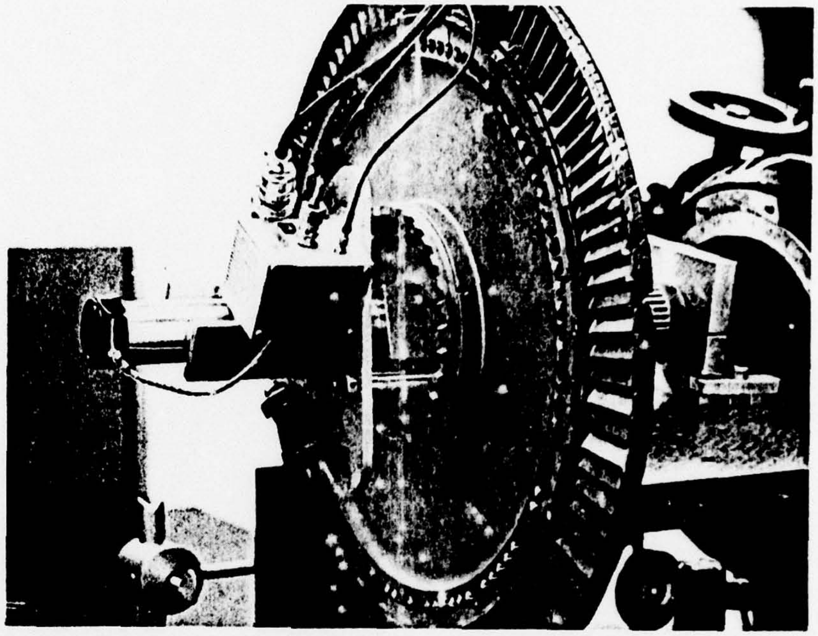

Figure 11: Impulser attached at hub of the series 3 wheel. Rectangular load distribution block is visible between the impulser and the wheel.

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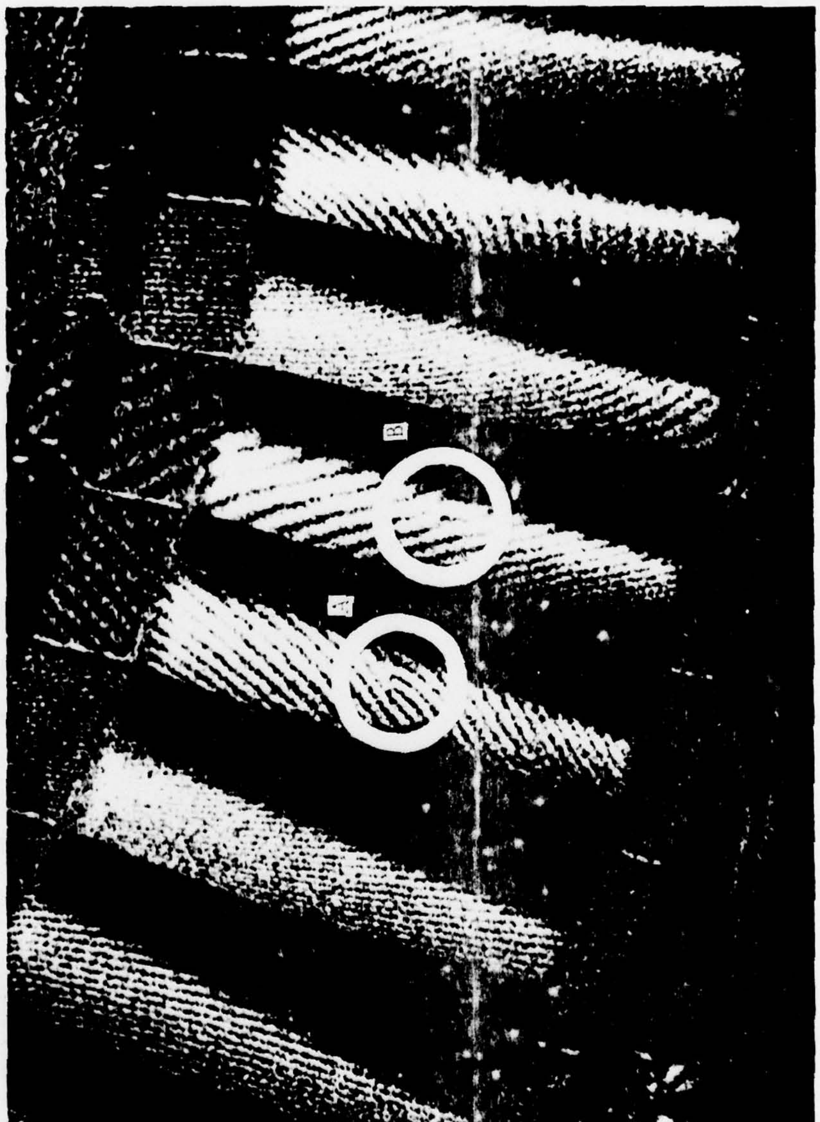

Figure 12: Holographic interferogram made after moving impulser to the hub of the wheel. Locations of the .075" deep "flaw" (A) and the .050" deep "flaw" (B) are circled.

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5.0 CONCLUSIONS AND RECOMMENDATIONS

Under this feasibility demonstration contract, the following was accomplished:

- The feasibility of employing pulsed laser holographic techniques with dynamic loading to inspect turbine blades was established.
- It was demonstrated that this inspection can be performed without disassembly of the turbine wheel.

As a result of this investigation, the following recommendations are made:

- Further investigation is needed to find a loading procedure which will optimize the sensitivity of this technique. Definition of an efficient means of introducing a dynamic load is an essential step in transferring this technology to a maintenance environment where laboratory controls are not present.
- The capabilities and limitations of this inspection technique must be fully evaluated prior to use in maintenance applications. Parameters such as flaw resolution, accuracy of flaw location, error rate, inspection time and cost should be determined and established.

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